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1.	Your reference	MPC/7887 GB 14JAN02 E687290-1 D00001 P01/7700 0.00-0200603.9
2.	Patent application number *(The Patent Office will fill in this part)*	11 JAN 2002 **0200603.9**
3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	BlazePhotonics Limited Finance Office University of Bath The Avenue Claverton Down Bath BA2 7AY United Kingdom
	08141129001 Patents ADP number *(if you know it)*	
	If the applicant is a corporate body, give the country/state of its incorporation	United Kingdom
4.	Title of the invention	Optical-fibre devices
5.	Name of your agent *(if you have one)*	Abel & Imray
	"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	20 Red Lion Street London WC1R 4PQ
	Patents ADP number *(if you know it)*	174001
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7.	If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application	Number of earlier application / Date of filing *(day/month/year)*
8.	Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if: a) any applicant named in part 3 is not an inventor, or b) there is an inventor who is not named as an applicant, or c) any named applicant is a corporate body. See note (d))*	Yes

9.	Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same documents.	
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	Priority documents	
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	Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	
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11.		I/We request the grant of a patent on the basis of this application.
		Signature: Abel & Imray (signed Abel & Imray) — Date: 11 January 2002
12.	Name and daytime telephone number of person to contact in the United Kingdom	Matthew Critten (01225) 469914

Optical-fibre devices

This invention relates to the field of optical-fibre devices and in particular to optical-fibre devices for altering the polarisation of an optical signal.

Optical fibres are important components of several technologies, in particular telecommunications. Optical fibres are usually made entirely from solid materials such as glass, and each fibre usually has the same cross-sectional structure along its length. Transparent material in one part (usually the middle) of the cross-section has a higher refractive index than material in the rest of the cross-section and forms an optical core within which light is guided by total internal reflection. We refer to such a fibre as a conventional fibre or a standard fibre.

Most standard fibres are made from fused silica glass, incorporating a controlled concentration of dopant, and have a circular outer boundary that is typically of diameter 125 microns. Standard fibres may be single-mode or multimode. Particular standard fibres may have particular properties, such as having more than one core or being polarisation-maintaining or dispersion compensating.

Standard fibres are in widespread and routine use and a wide range of devices based on standard fibres have been developed.

Most recent fibre-based long-range communications devices operate in a wavelength band between about 1510 nm and 1600 nm. That band provides low attenuation compared with another available band around 1310 nm but causes chromatic dispersion of optical signals. Chromatic dispersion is a phenomenon in which light of different wavelengths travels at different speeds in a medium. Light in the 1510 nm - 1600 nm wavelength band experiences 'anomalous' dispersion in a standard optical fibre (that means that shorter wavelengths travel faster than longer wavelengths). Dispersion causes distortions of optical

signals, such as pulse broadening. Its effects can be ameliorated by periodically passing the optical signal through a region having dispersion of the opposite sense, for example by passing the light through a fibre having 'normal' dispersion (that means that longer wavelengths travel faster than shorter wavelengths). Such dispersion-compensating fibre (DCF) is well known.

Of course, dispersion compensation may be desirable at other wavelengths and in other applications, for example in pulsed laser devices.

A typical single-mode standard fibre may in fact support two transverse modes, differing in the polarisation direction of the light they contain. The two modes correspond to light having two orthogonal polarisations.

Fibre-based dispersion compensation modules (DCMs) are subject to polarisation mode dispersion (PMD). That effect, which worsens the longer the fibre becomes, is caused by random fluctuations in the properties of the DCF with temperature and stress. Those fluctuations result in a time-dependent group velocity delay between the two eigen-states of the fibre, which is also highly wavelength dependent. The effect becomes more and more serious as the pulse lengths get shorter, i.e., the system capacity becomes larger. Systems designers are very keen to obtain DCMs in which the PMD is completely deterministic; i.e., it does not fluctuate with time. That is possible if a polarisation-maintaining fibre is used; a polarisation-maintaining fibre provides a fixed amount of birefringence that is very much larger than any random fluctuations and thereby ensures that the group delay between states is essentially constant. The delay may then be readily compensated for.

Recently a new type of optical fibre has been developed known as a photonic crystal fibre (PCF; also known as a microstructured fibre or a holey fibre).

PCFs are fibres having a cladding region that comprises a plurality of elongate regions, running parallel to the

longitudinal axis of the fibre, that are of a different refractive index from a matrix region in which they are embedded. The elongate regions are, in many cases, air-filled holes, although they are in some cases solid regions or regions filled with a liquid or another gas.

The core of a PCF is a region having a different structure from the cladding region; it is often a region having no holes or a region having one or more extra holes.

Light is confined to the core of a PCF by the cladding through the action of one of two mechanisms. The first is closely related to the guidance mechanism of a standard fibre. In this mechanism, the matrix regions and the elongate regions of the cladding have an 'effective' refractive index that is less than the refractive index of the core region, so that total internal reflection occurs and traps light in the core. (The 'effective' refractive index of the cladding region can readily be calculated by a person skilled in the art; in general, its exact value depends upon the shape of the mode guided in the core but its value will be between that of the elongate regions and that of the matrix regions.)

In the second mechanism, the arrangement of elongate regions in the cladding is periodic such that they form a photonic band gap. (This phenomenon is analogous to the formation of electronic band gaps in semiconductors.) Interference between light reflected from the elongate regions is such that there are certain bands of frequencies that cannot propagate in the cladding. The core of a PCF that guides by this mechanism forms a 'defect' in the periodic structure of the cladding; light can propagate in this defect region. Light is thus confined to and propagates in the core of the PCF.

The term 'photonic crystal fibre' reflects the historical roots of the structure of the fibres; the fibres were developed with a view to demonstrating the band-gap guidance mechanism. However, we refer to all fibres having such elongate regions as photonic crystal fibres, even if they do

not have band-gaps and guide by the first mechanism, index guiding. In particular, the term is not restricted to fibres having periodic arrangements of elongate regions in their claddings.

Polarisation-maintaining fibre in PCF is attractive because it is potentially very low loss (limited only by the Rayleigh scattering loss of pure silica glass, roughly 0.2 dB/km) and is far less sensitive to environmental fluctuations than a standard fibre. Examples of highly birefringent polarisation-maintaining fibres are described in International Patent Application No. PCT/GB00/00600 (in the name of The University of Bath *et al*. and published as WO 00/49436), which is hereby incorporated herein by reference. However, even a PCF that has not been specifically designed for high birefringence may have sufficient birefringence to be polarisation-maintaining due to imperfections in the arrangement of elongate regions in its cladding.

An object of the invention is to provide a device for and a method of altering the polarisation of light that is propagating in a PCF. A further object of the invention is to provide a device and method for reducing polarisation-mode dispersion in a photonic-crystal fibre.

According to the invention there is provided an optical fibre comprising a first longitudinal region and a second longitudinal region, the first and second regions each having a fast polarisation axis and a slow polarisation axis, characterised in that the polarisation axes of the first longitudinal region are rotated with respect to the polarisation axes of the second longitudinal region.

Preferably, the fibre is a photonic crystal fibre.

Preferably, the polarisation axes are rotated because the fibre includes a twist.

Highly birefringent standard fibres generally contain high internal stresses and twisting such a fibre would often destroy the fibre, although the invention may be applied to such a fibre. Imperfections in the arrangement of

longitudinal regions in a PCF typically results in even a PCF that has not been designed to be highly birefringent being sufficiently birefringent to be polarisation-maintaining. The internal stresses in a birefringent PCF are generally much lower than those of a birefringent standard fibre and a PCF may thus be twisted without it being destroyed.

Preferably, the fast polarisation axis of the first region is aligned with the slow polarisation axis of the second region. Preferably, the slow polarisation axis of the first region is aligned with the fast polarisation axis of the second region. Thus, light propagating in the fibre, which maintains its polarisation direction relative to the fibre's environment, effectively has its polarisation direction swapped relative to the polarisation axes of the fibre.

Preferably, the twist occurs over a length of the fibre that is less than the beat length of the fibre.

Preferably, the twist occurs over a length of the fibre that is sufficiently short that light polarised along the fast polarisation axis of the first region is transferred without leakage loss to the slow polarisation axis of the second region. Preferably, the twist occurs over a length of the fibre that is sufficiently short that light polarised along the slow polarisation axis of the first region is transferred without leakage loss to the fast polarisation axis of the second region. Suitable lengths in any given embodiment may readily be determined by the skilled person. A smooth transition results in essentially lossless polarisation switching.

Preferably, the twist is at the centre of the length of the fibre. When the twist is provided halfway along the fibre, the fibre may have a deterministically very small group delay; at the twist, light swaps over between polarisation states in a wavelength-insensitive manner and at the output of the fibre the two pulse components, of orthogonal polarisation, arrive at exactly the same moment, eliminating group delay to within the accuracy of the fibre length.

Furthermore, in a polarisation-maintaining PCF, the group delay will typically not vary significantly with temperature since polarisation-maintaining PCF is not vulnerable to stress-induced changes in birefringence. An additional advantage is that PCF is intrinsically insensitive to environmental effects.

Preferably, the photonic crystal fibre comprises a plurality of twists, such that there is at least one further longitudinal region having its axes rotated with respect to the axes of an adjacent longitudinal region such that the fast polarisation axis of the further region is aligned with the slow polarisation axis of the adjacent region.

As an alternative to the sharp twist required to swap the polarisation axes of the fibre, the axes of the first region may be rotated with respect to the axes of the second region by only a small amount. Preferably, the fibre contains a plurality of twists, such that there is at least one further longitudinal region having its axes rotated by only a small amount with respect to the axes of an adjacent longitudinal region. Preferably, the axes of adjacent longitudinal regions defined by the twists are rotated in opposite directions. Preferably, the axes of adjacent longitudinal regions defined by the twists are rotated by angles of equal magnitude. More preferably the longitudinal regions have a length that is equal to one half of their beat length.

In this alternative embodiment, the plurality of twists may thus form a 'rocking' filter, in which light is gradually transferred from one polarisation to the other by the twisting of the axes of adjacent regions in opposite directions.

Provision of a small number (perhaps five to ten) of such longitudinal regions that are each rotated by a relatively large angle (perhaps five to ten degrees) may be used to provide a filter with a wide bandwidth.

Preferably, the twists each occur over a length of the fibre that is sufficiently short that light is transferred without leakage loss between adjacent longitudinal regions.

The polarisation axes of the fibre according to the invention may be rotated because the fibre comprises two spliced fibres that are rotated relative to each other.

Preferably, the rotation is such that the fast polarisation axis of the first region is aligned with the slow polarisation axis of the second region.

Preferably, the splice is at the centre of the fibre.

Preferably, the splice is a fusion splice. Preferably a transition region is provided adjacent to the splice, in which the strength of birefringence falls from its usual value in the first and second fibres to zero at the splice. Such a transition region may improve the loss properties of the splice.

Preferably, the fibre is connected at each end to a single-mode fibre. Preferably, the connection is via a taper.

As discussed above, polarisation-mode dispersion is a particular problem in dispersion-compensation modules employing a standard fibre. The fibre according to the invention may exhibit anomalous chromatic dispersion or normal chromatic dispersion. Also according to the invention there is provided a dispersion compensation module comprising such a fibre.

Many other optical devices incorporating a photonic crystal fibre as described above as being in accordance with the invention are envisaged. For example, also according to the invention, there is provided an optical coupler or splitter or an interleaver comprising a fibre described above as according to the invention. A measuring device may also be provided incorporating a fibre according to the invention.

Also according to the invention there is a method of manufacturing an optical fibre for altering the polarisation of propagating light, comprising rotating a part of an optical fibre to create a first longitudinal region and a second longitudinal region, the first and second regions each having a fast polarisation axis and a slow polarisation axis, the rotation being such that the polarisation axes of the first

longitudinal region are rotated with respect to the polarisation axes of the second longitudinal region.

Preferably, the rotation is a rotation of 90°.

Preferably, the fibre is a photonic crystal fibre.

Preferably, the rotation is achieved by heating a portion of the fibre and twisting the fibre in the heated portion.

Such a twist may not readily be provided in a standard fibre because induced stresses are likely to destroy the fibre.

Preferably, the heating and twisting occurs during drawing of the fibre from a preform. Alternatively, the heating and twisting takes place after the fibre has been drawn from a preform.

The heating may be carried out using any suitable means, such as a CO_2 laser or a flame.

Alternatively, the rotation may be achieved by providing a first optical fibre and a second optical fibre, the first and second fibres each having a fast polarisation axis and a slow polarisation axis, and splicing the first fibre and the second fibre together such that the polarisation axes of the first fibre are rotated with respect to the polarisation axes of the second fibre.

Preferably, the splice is a fusion splice.

Preferably, a transition region is provided adjacent to the splice, in which the strength of birefringence falls from its usual value in the first and second fibres to zero at the splice. Such a transition region may improve the loss properties of the splice. The transition region may be provided by heat treatment either before or after the splicing. Heat treatment may be used to make the fibre adjacent to the splice optically circularly symmetric. In the case of a PCF, that may be achieved for example by causing the collapse of hole structures providing the birefringence and in a standard fibre it may cause dopant diffusion to circularise the core and/or to eliminate stress birefringence.

Preferably, the first and second optical fibres are photonic crystal fibres. Although this splicing technique may be applied to a standard fibre, it would preferably be applied to a photonic crystal fibre, because polarisation-maintaining standard fibres are expensive and generally do not provide simultaneous dispersion compensation.

Preferably, the first fibre and the second fibre are provided by cleaving a fibre into two portions.

The photonic crystal fibre may be drawn from a preform comprising a bundle of rods, the rods being arranged to form a core region and a cladding region surrounding the core region, the cladding region comprising a plurality of elongate regions embedded in a matrix region. The elongate regions may be, for example, holes formed from rods that are capillaries.

Also according to the invention there is provided an optical fibre comprising a first longitudinal region and a second longitudinal region, the first and second regions each having a fast polarisation axis and a slow polarisation axis, characterised in that the fibre comprises two spliced fibres that are rotated relative to each other at the splice, such that the polarisation axes of the first longitudinal region are rotated with respect to the polarisation axes of the second longitudinal region.

Preferably, the optical fibre is a photonic crystal fibre.

Also according to the invention there is provided a method of propagating a light signal, comprising propagating the light along a fibre described above as being according to the invention, wherein the polarisation of the light is rotated at the, or at the first, rotation of the polarisation axes of the fibre (for example, at the, or at the first, twist or splice).

Preferably, the polarisation of the light is in a first principal state of polarisation before reaches the, or the first, rotation of the polarisation axes of the fibre and it

is in a second principal state of polarisation when it leaves the rotation or the last such rotation.

Also according to the invention there is provided a method of compensating for polarisation mode dispersion, comprising propagating a light signal along a first region of a fibre and then propagating the light signal along a second region of the fibre of equal length to the first region, characterised in that the polarisation of components of the light signal is rotated between the first and second regions, relative to the fast and slow polarisation axes of the fibre.

Preferably, the rotation results because the fast and slow polarisation axes of the first region are aligned with the slow and fast polarisation axes, respectively, of the second region.

Alternatively, the rotation results from the effect of a rocking filter provided between the first and second regions.

According to the invention there is provided a device comprising first and second fibre portions, both having at least a fast and a slow polarisation axis, there being provided a region optically coupling the first and second fibre portions for coupling light from the first fibre portion travelling in the fast and slow polarisation axes to the slow and fast polarisation axes respectively of the second fibre portion such that polarisation dependent effects of the first fibre portion are substantially compensated for by polarisation dependent effects of the second fibre portion.

The polarisation dependent effects may be, for example, PMD or other birefringence-related polarisation effects.

Embodiments of the invention will now be described, by way of example only, with reference to the drawings, of which:

Fig. 1 is a photonic crystal fibre according to the invention;

Fig. 2 is a polarisation mode dispersion compensation unit including the fibre of Fig. 1;

Fig. 3 is a second photonic crystal fibre according to the invention.

Fig. 4 is a third photonic crystal fibre according to the invention.

In an embodiment of the invention, photonic crystal fibre 10 includes, in a transverse cross-section, a cladding region 30 formed from a plurality of elongate holes 40 arranged in a triangular lattice pattern in a silica matrix material. At the centre of the holes 40, an air hole is missing from the lattice, there being instead a region of silica that forms a core region 20. The cladding region 30 confines light to the core region 20 because the air holes 40 result in the cladding region 30 having a lower effective refractive index than the solid silica core region 20 so that total internal reflection can occur between the core region 20 and the cladding region 30. The fibre 10 also includes a jacket region 50, which is provided to provide the fibre with mechanical strength and protection.

On opposite sides of, and adjacent to, core region 20 there are two groups of holes 90 that are larger than the other holes 40. These larger holes act to make the fibre 10 birefringent, with a first (fast) principal axis F running through holes 90 and a second (slow) principal axis S running at right angles to the first axis. In region 80, axes F and S have effectively been interchanged compared with their directions in region 60 because of the ninety degree rotation of region 80, which results in a rotation of holes 90 by ninety degrees about the core region 20.

Fibre 10 is divided into two longitudinal regions 60 and 80 that are of equal length and are separated by a twisted region 70. The twist is provided by placing fibre 10 on a fibre tapering rig, of a type well known in the art for tapering standard fibres. Region 70 is heated until the silica softens and then length 80 is rotated by ninety degrees in a rotatable chuck. The beat length of this (highly birefringent) fibre is about 500 microns at 1.55 nm. The length of region 70 is about 100 microns, which is sufficiently short for light propagating in the fibre 10 to

pass adiabatically (that is, without loss) from region 60 to region 80.

Symbols marked A, B and C in Fig 1 represent the polarisation properties of the fibre 10. The bow-tie shape in each of A, B and C indicates, by the direction of the bow tie's longitudinal axis, the direction of polarisation axis S of the fibre in regions 60, 70 and 80 respectively. The double headed arrows represents the polarisation direction of linearly polarised light propagating in the fibre.

In region 60, propagating light is linearly polarised along polarisation axis S. In the twist 70, the polarisation axes are interchanged, as discussed above. The polarisation of the propagating light does not change in its passage from region 60 into region 80. However, as described above, the polarisation axes of fibre 10 have swapped. In region 80, the propagating light is therefore linearly polarised along polarisation axis F.

Fibre 10 may be used in a dispersion compensation module 100 (Fig. 2) to provide chromatic dispersion compensation with negligible polarisation mode dispersion. In module 100, single mode-fibres 110, 140 are connected to photonic crystal fibre 10 by a taper regions 120, 130.

A pulse having an arbitrary, linear polarisation is propagating along standard telecomms single mode fibre 110. The pulse passes though the taper region 110, enters fibre 10 and propagates in region 60. In region 60, the pulse will split into two components, one being linearly polarised along axis F and the other being linearly polarised along axis S. As the components propagate, the component linearly polarised along axis S will lag behind the other component. However, after twist 70, the component formerly polarised along axis S will be polarised along axis F in region 80. Twist 70 is at the centre of fibre 10 and therefore when the pulse components reach transition region 130 at the end of the fibre, the component that was lagging prior to the twist will have exactly caught up with the other component and so the original

linear polarisation of the pulse at it left standard fibre 110 will be restored as it enters standard telecomms fibre 140.

Photonic-crystal fibre 10 provides anomalous dispersion of 20 ps/nm/km. Provision of twist 70 means that that dispersion compensation may be provided with almost no polarisation mode dispersion. This approach will also eliminate polarisation-dependent loss.

In an alternative embodiment (Fig. 3), the twist in the first embodiment is replaced by a simple splice 150 of two component fibres 160, 170, wherein the polarisation axes of the two fibres 160, 170 are rotated by 90 degrees with respect to each other where the splice 150 is made. Transition regions 180, 190 are provided around the splice 150, in which the strength of birefringence in each component fibre 160, 170 is reduced from its usual value to zero at a non-birefringent midpoint at the splice 150, as shown schematically in Fig. 3 (b) and (c). Because the reduction and subsequent increase of the birefringence is gradual, the transition is adiabatic. The transition regions 180, 190 are formed by heat-treating the component fibre 160, 170 to produce circular symmetry at the point at which the component fibre 160, 170 is to be cleaved.

The strength of birefringence is represented in two ways in Fig. 3: by the size of the "bow-tie" in Fig. 3 (c) and by the ellipticity of a schematic fibre core in Fig. 3 (b). A PCF core will not in general be elliptical but the representation is useful to illustrate the strength of anisotropy.

In another alternative embodiment of the invention, the twist 70 of fibre 10 is replaced with a 'rocking filter' (Fig. 4). Fibre 200 comprises, in its transverse cross-section, a cladding region 230 comprising a plurality of holes 240 that are arranged on a triangular lattice pattern. In this embodiment, the holes form a photonic band-gap that prevents propagation of light at around 1550 nm in the cladding 230. The lattice pattern is broken by a defect in the form of an enlarged hole 220, which forms a core region. Light at 1550 nm can propagate in the core region and it is confined to the

core region by the band-gap of the cladding region. A jacket region 240 is provided for mechanical strength and protection.

Imperfections in the arrangement of holes 240 cause fibre 200 to be birefringent. Fibre 200 is dispersive because light of longer wavelengths will spread further out from the core of the fibre and into the cladding than light of shorter wavelengths.

Along its length, fibre 270 is divided into longitudinal region 260, which has polarisation axes that are in a fixed direction (symbol D), rocking filter region 270 and longitudinal region 290, which has polarisation axes (symbol N) that are fixed in the same direction as those of region 260. Rocking filter 270 comprises ten short longitudinal regions 271-280, each about 1 mm in length, which have polarisation axes that are rotated by five degrees either side of the polarisation axes of regions 260 and 290, with alternate sections being rotated clockwise (odd figure numbers) looking from region 260 to region 290 and anti-clockwise (even figure numbers).

Optimal coupling is given when

$$\kappa L = \frac{\pi}{2}$$

where L is the coupling length and κ is the coupling constant

$$\kappa = \frac{2\pi\theta}{L_B}$$

where θ is the angle of rotation and L_B is the beat length

$$L_B = \frac{\lambda}{|n_S - n_F|}$$

where λ is the wavelength of the propagating light (in this case 1550 nm) and $n_S - n_F$ is the difference between the refractive indices of the slow axis and the fast axis in the region. Hence the relationship between the length of longitudinal region and the angle of rotation required is given by:

$$\therefore \theta L = \frac{L_B}{4}.$$

Rocking filter 270 is made in a similar manner to twist 70. The fibre is placed in a drawing rig, region 260 is clamped in place and then region 290 is rotated relative to region 260 to form twist 271. Unlike in the case of fibre 10, however, the rotation is by only 5 degrees. The fibre 270 is cooled and the re-clamped at region 271. Region 272 is formed by heating that region of the fibre and rotating it by ten degrees in the opposite sense to the twist that formed region 270 (i.e., clockwise instead of anticlockwise or *vice versa*). The fibre 270 is again cooled and then region 273 is formed by heating that region of the fibre and rotating it by ten degrees in the direction of the rotation that formed twist 271. The cooling, heating and twisting is repeated to form all of regions 271-280. The twists 271-280 together form, along the length of the fibre 270, a sinusoidal variation of the direction of the polarisation axes of the fibre.

The behaviour of light propagating in fibre 200 may be understood with the aid of symbols D to O.

In region 260, propagating light is linearly polarised along polarisation axis S. When the light passes into twist 271, the small rotation of the polarisation axes means that the light is split into two components, polarised along the new axes. The majority of the light is polarised along the rotated S axis but a small fraction (sin $\delta\theta$, where $\delta\theta$ = 5 degrees in this example) is polarised along the rotated F axis. The length of each of the regions 271 to 280 is equal to half of the beat length L_B for that region. A full period of the sinusoidal variation provided by the twisting (i.e., two of regions 271 to 280) is thus equal to the beat length. Consequently, the light passes into twist 272 when the light transferred onto the fast axis is at a maximum. A similar effect occurs in region 272 and is repeated in each of regions 273 to 280. As each region has a length of half its beat length, the effects of the transfers reinforce each other and

when light reaches region 280, its polarisation has been entirely transferred to the fast polarisation axis.

A rocking filter 270 acts as a passband polarisation filter, transferring light around wavelength λ from one polarisation to an orthogonal polarisation. The filter 270 is arranged so that all wavelengths of interest are completely transferred between polarisation states.

A rocking filter 270 may be used in a dispersion compensation module such as that of Fig. 2 instead of ninety-degree twist 70. The rocking filter 270 has the same effect as the ninety-degree twist in that it rotates the polarisation of light by ninety degrees relative to the polarisation axes of the fibre. The rocking filter 270 does that by rotating the polarisation of the light, whereas the twist 70 does it by rotating the polarisation axes.

(A photonic crystal that guides by a photonic band-gap is used in the embodiment of Fig. 4 by way of illustration of an alternative to the total-internal reflection photonic crystal fibre of Fig. 1. Of course, either guidance mechanism may be employed in a fibre having either polarisation-changing mechanism (a twist 70 or a rocking filter 270).)

The sharply twisted fibre of the first and second embodiments (Figs. 1, 2 and 3) switches the polarisations of all wavelengths propagating in the fibre, whereas the rocking filter of the second embodiment is wavelength sensitive and only switches wavelengths in a passband. A wavelength-dependent polarisation coupler may therefore readily be provided using the rocking filter embodiment.

Claims

1. An optical fibre comprising a first longitudinal region and a second longitudinal region, the first and second regions each having a fast polarisation axis and a slow polarisation axis, characterised in that the polarisation axes of the first longitudinal region are rotated with respect to the polarisation axes of the second longitudinal region.

2. A fibre as claimed in claim 1, which is a photonic crystal fibre.

3. A fibre as claimed in claim 1 or claim 2, in which the polarisation axes are rotated because the fibre includes a twist.

4. A fibre as claimed in claim 3, in which the fast polarisation axis of the first region is aligned with the slow polarisation axis of the second region.

5. A fibre as claimed in claim 4, in which the twist occurs over a length of the fibre that is sufficiently short that light polarised along the fast polarisation axis of the first region is transferred without leakage loss to the slow polarisation axis of the second region.

6. A fibre as claimed in claim 3 or claim 4, in which the twist is at the centre of the length of the fibre.

7. A fibre as claimed in claim 3, in which the axes of the first region are rotated with respect to the axes of the second region by only a small amount.

8. A fibre as claimed in claim 7, in which the fibre contains a plurality of twists, such that there is at least one further longitudinal region having its axes rotated by only a small amount with respect to the axes of an adjacent longitudinal region.

9. A fibre as claimed in claim 8, in which the axes of adjacent longitudinal regions defined by the twists are rotated in opposite directions.

10. A fibre as claimed in claim 8 or claim 9, in which the axes of adjacent longitudinal regions defined by the twists are rotated by angles of equal magnitude.

11. A fibre as claimed in claim 10, in which the longitudinal regions have a length that is equal to one half of their beat length.

12. A fibre as claimed in claim 11, in which the twists each occur over a length of the fibre that is sufficiently short that light is transferred without leakage loss between adjacent longitudinal regions.

13. A fibre as claimed in claim 1 or claim 2, in which the polarisation axes are rotated because the fibre comprises two spliced fibres that are rotated relative to each other at the splice.

14. A fibre as claimed in claim 13, in which the rotation is such that the fast polarisation axis of the first region is aligned with the slow polarisation axis of the second region.

15. A fibre as claimed in claim 13 or claim 14, in which the splice is at the centre of the fibre.

16. A fibre as claimed in any of claims 1 to 15, which is connected at each end to a single-mode fibre.

17. A fibre as claimed in claim 16, in which the connection is via a taper.

18. A fibre as claimed in any preceding claim that exhibits anomalous chromatic dispersion.

19. A fibre as claimed in any of claims 1 to 18 that exhibits normal chromatic dispersion.

20. An optical coupler or splitter comprising a fibre according to any of claims 1 to 19.

21. An interleaver for a wave-division multiplexed optical signal comprising a fibre according to any of claims 1 to 18.

22. A dispersion compensation module comprising a fibre according to claim 18 or claim 19.

23. A method of manufacturing an optical fibre for altering the polarisation of propagating light, comprising rotating a part of an optical fibre to create a first longitudinal region

and a second longitudinal region, the first and second regions each having a fast polarisation axis and a slow polarisation axis, the rotation being such that the polarisation axes of the first longitudinal region are rotated with respect to the polarisation axes of the second longitudinal region.

24. A method as claimed in claim 23, in which the rotation is a rotation of 90°.

25. A method as claimed in claim 23 or claim 24, in which the fibre is a photonic crystal fibre.

26. A method as claimed in claim 24 or claim 25 in which the rotation is achieved by heating a portion of the fibre and twisting the fibre in the heated portion.

27. A method as claimed in claim 26, in which the heating and twisting occurs during drawing of the fibre from a preform.

28. A method as claimed in claim 26 or claim 27, in which the heating and twisting takes place after the fibre has been drawn from a preform.

29. A method as claimed in claim 24 or claim 25, in which the rotation is achieved by providing a first fibre and a second fibre, the first and second fibres each having a fast polarisation axis and a slow polarisation axis, and splicing the first fibre and the second fibre together such that the polarisation axes of the first fibre are rotated with respect to the polarisation axes of the second fibre.

30. A method as claimed in claim 29, in which the first and second fibres are photonic crystal fibres.

31. A method as claimed in claim 29 or claim 30, in which the first fibre and the second fibre are provided by cleaving a fibre into two portions.

32. A method of propagating a light signal, comprising propagating the light along a fibre according to any of claims 1 to 19, wherein the polarisation of the light is rotated at the, or at the first rotation of the polarisation axes of the fibre.

33. A method as claimed in claim 32, in which the polarisation of the light is in a first principal state of

polarisation before reaches the, or the first, rotation of the polarisation axes of the fibre and it is in a second principal state of polarisation when it leaves the rotation or the last such rotation.

34. A method of compensating for polarisation mode dispersion, comprising propagating a light signal along a first region of a fibre and then propagating the light signal along a second region of the fibre of equal length to the first region, characterised in that the polarisation of components of the light signal is rotated between the first and second regions, relative to the fast and slow polarisation axes of the fibre.

35. A method as claimed in claim 34, in which the rotation results because the fast and slow polarisation axes of the first region are aligned with the slow and fast polarisation axes, respectively, of the second region.

36. A method as claimed in claim 34, in which the rotation results from the effect of a rocking filter provided between the first and second regions.

37. A device comprising first and second fibre portions, both having a fast and a slow polarisation axis, there being provided a region optically coupling the first and second fibre portions for coupling light from the first fibre portion travelling in the fast and slow polarisation axes to the slow and fast polarisation axes respectively of the second fibre portion such that polarisation dependent effects of the first fibre portion are substantially compensated for by polarisation dependent effects of the second fibre portion.

38. A device as claimed in claim 37, in which the polarisation dependent effect is polarisation mode dispersion.

39. A method substantially as herein described with reference to the accompanying drawings.

40. A fibre substantially as herein described, with reference to the accompanying drawings.

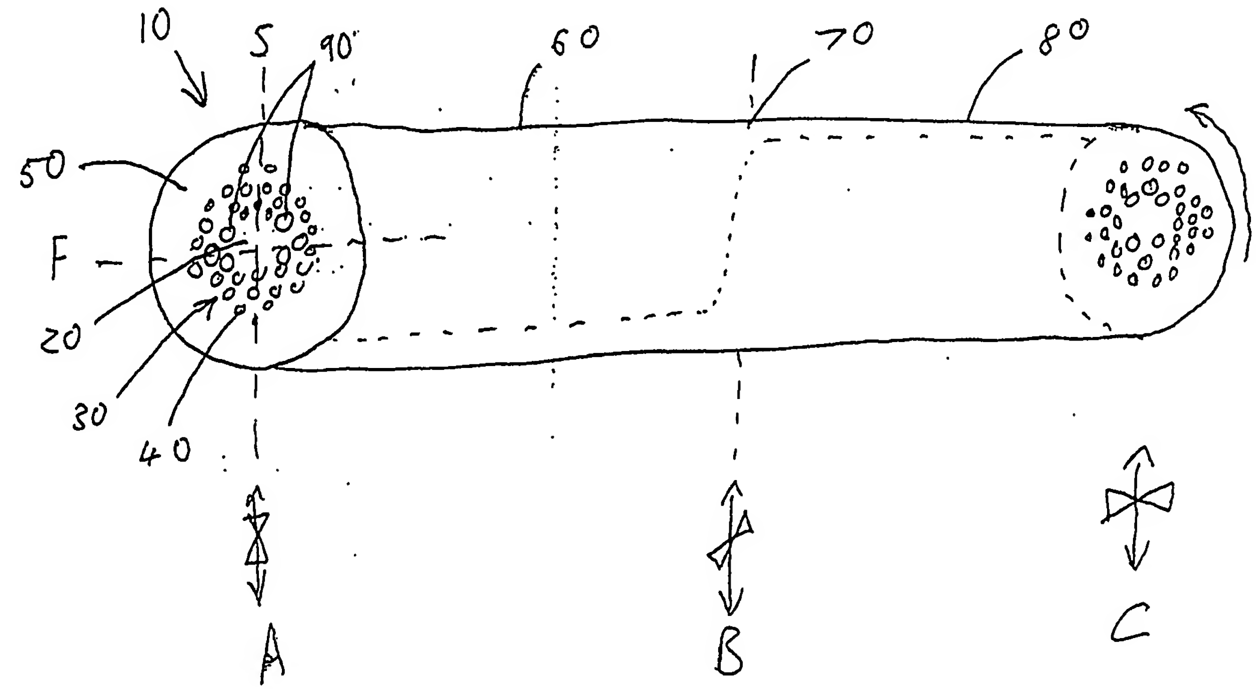


Fig. 1

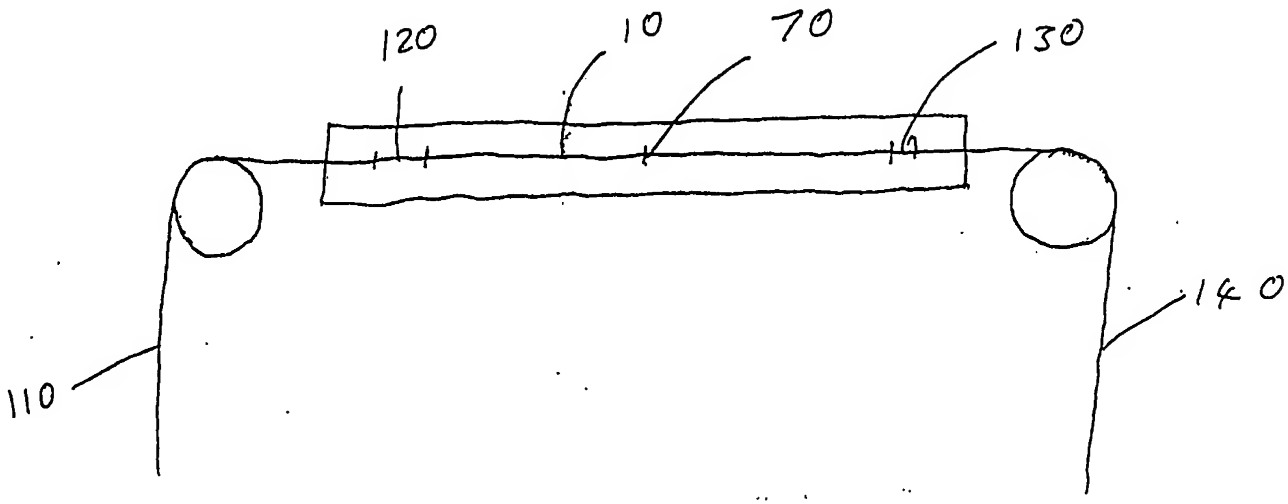


Fig. 2

Fig. 3

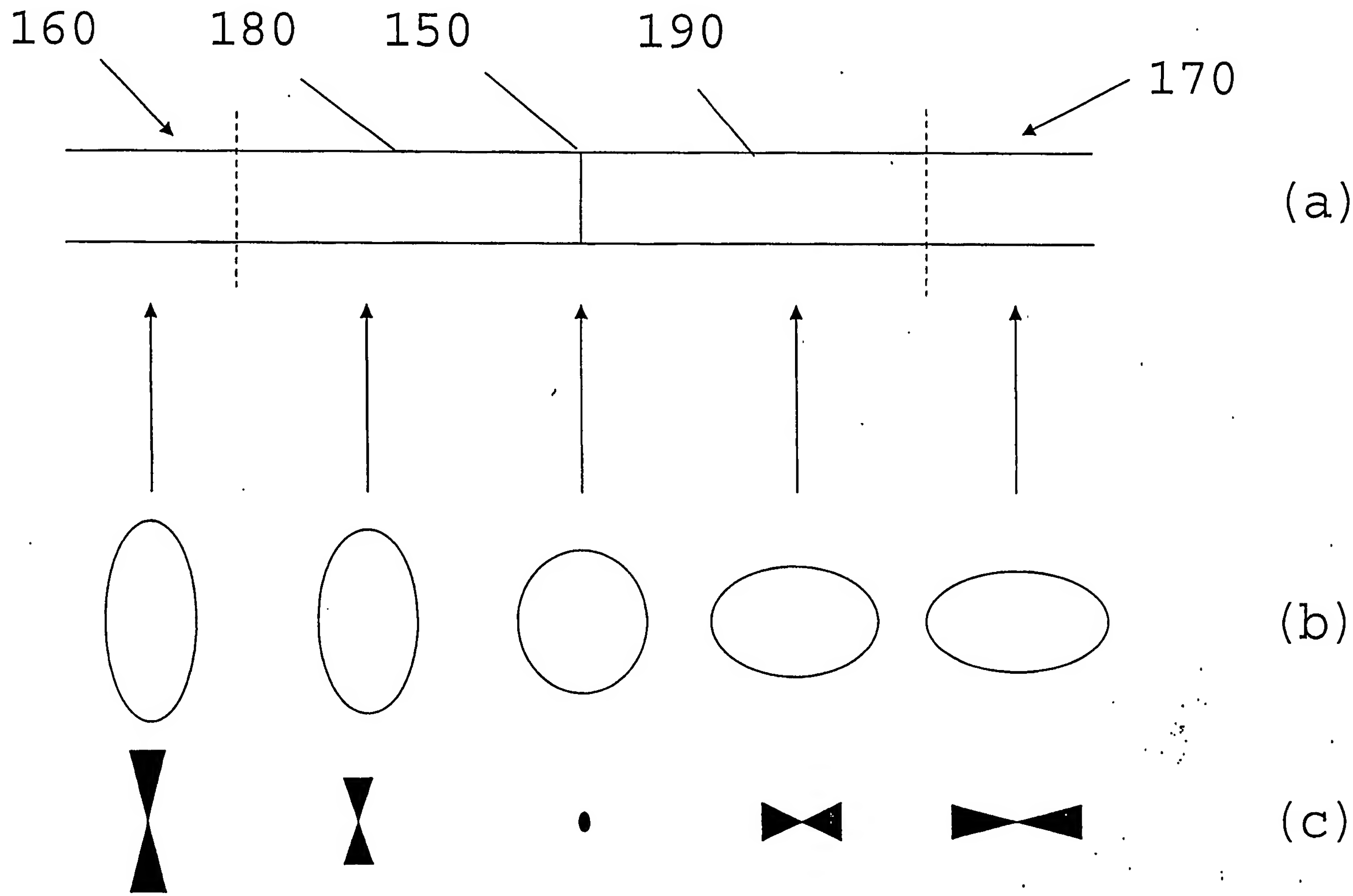
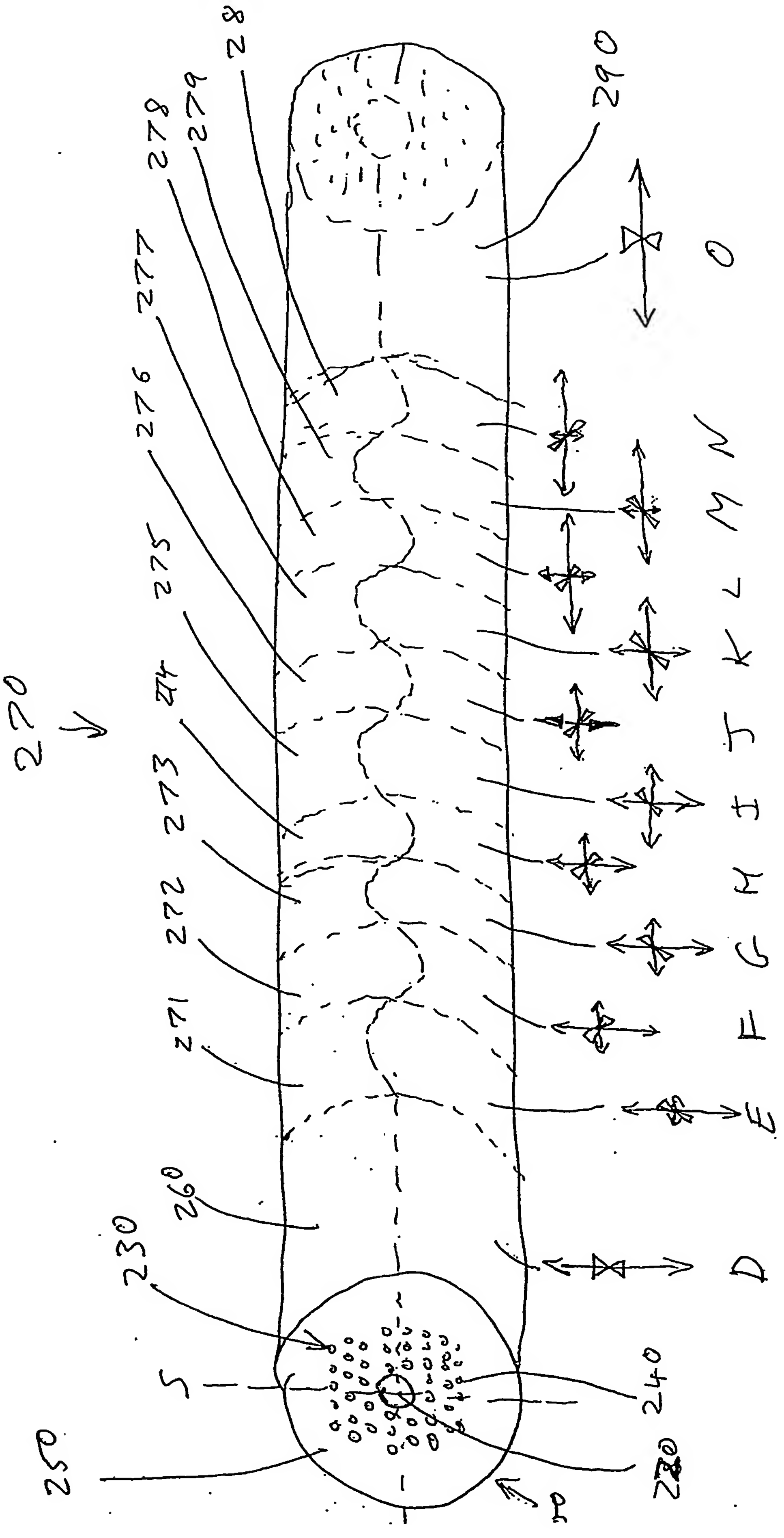


Fig. 4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